Fermi National Accelerator Laboratory

FERMILAB-Conf-94/063-E

CDF

W Charge Asymmetry Measurement and Z' Search at CDF

Kaori Maeshima
For the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

March 1994

Published Proceedings *9th Topical Workshop on Proton-Antiproton Collider Physics,* University of Tsukuba, Tsukuba, Japan, October 18-22, 1993

Disclaimer

CDF/PUB/ELECTROWEAK/PUBLIC/2351
FERMILAB-CONF-94/063-E

W Charge Asymmetry Measurement and Z' Search at CDF

Kaori Maeshima
Fermi National Accelerator Laboratory
For the CDF Collaboration

Published Proceedings 9th Topical Workshop on Proton-Antiproton Collider Physics, University of Tsukuba, Tsukuba, Japan, October]8-22, 1994

Abstract

The charge asymmetry as a function of lepton rapidity, $A(y_l)$, has been measured at $\sqrt{s} = 1.8$ TeV for $|y_l| < 1.8$, using the W decays to electrons and muons recorded by CDF during the 1992-93 run of the Tevatron Collider. Compared to the previous 1988-89 run, the increase in luminosity and detector improvements have lead to a six fold increase in statistics making discrimination between sets of parton distributions possible. Our data favors the most recent parton distributions and demonstrates the value of collider data in the measurement of the proton's structure. We also present here a search for an additional neutral heavy boson, Z', in the dielectron decay mode. The observed dielectron invariant mass spectrum is in good agreement with that expected from the decays of the standard Z and from the Drell-Yan process. We obtain a 95% c.l. limit on the production cross section times the branching ratio for a Z' decaying into electron pairs as a function of the dielectron invariant mass. We also set a 95% confidence level lower bound on the mass of the Z' to be 495 GeV/c^2 assuming standard coupling strengths.

1. Introduction

The CDF collaboration has collected approximately 20 pb^{-1} data during the 1992-93 running period. Using the data, we report here on a result of the W charge asymmetry study and a search for direct production of heavy neutral gauge bosons in the *ee* mode.

A detailed description of the Collider Detector at Fermilab (CDF) may be found elsewhere [1]; the components relevant for this analysis are described briefly here. We use a coordinate system with z along the proton beam, azimuthal angle ϕ, polar angle θ, and pseudorapidity $\eta = -\ln\tan(\theta/2)$. A central tracking chamber (CTC) measures charged particle momenta for $|\eta| < 1.2$. Scintillator-based electromagnetic (EM) and hadronic (HAD) calorimeters in the central region ($|\eta| < 1.1$) are arranged in projective towers of size $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.26$. Gas-based calorimeters cover the plug ($1.1 < |\eta| < 2.4$) and forward ($2.4 < |\eta| < 4.2$) regions. The central electromagnetic strip chambers (CES) are multiwire proportional chambers embedded inside the central EM calorimeter near shower maximum. Outside the central calorimeters, the region $|\eta| < 0.63$ is instrumented with four layers of drift chambers for muon detection.

2. W Charge Asymmetry

W^+ (W^-) bosons are produced in $p\overline{p}$ collisions primarily by the annihilation of u (d) quarks from the proton and $\overline{d}$ ($\overline{u}$) quarks from the antiproton. Because the u quark tends to carry a larger fraction of the proton's momentum than the d quark the W^+ (W^-) tends to be boosted in the proton (antiproton) direction. The charge asymmetry in the production of W's, as a function of rapidity, is therefore related to the difference in the quark distributions at very high Q^2 ($\approx M_W^2$) and low x ($0.007 < x < 0.24$).

The Drell-Yan events are easily reconstructed from the measured properties of the decay leptons. However, the W decay involves a neutrino, whose longitudinal momentum is undetermined. Therefore the quantity measured is the charge asymmetry of the decay leptons, which has an added contribution due to the V-A decay of the W. This portion of the asymmetry has been well measured by muon decay experiments; thus in comparisons to theory, one can attribute any deviations (between prediction and measurement) to the parton distributions used in the calculations. The asymmetry is defined as:

$$A(y_l) = \frac{d\sigma^+/dy_l - d\sigma^-/dy_l}{d\sigma^+/dy_l + d\sigma^-/dy_l} \qquad (1)$$

where $d\sigma^+$ ($d\sigma^-$) is the cross section for W^+ (W^-) decay leptons as a function lepton rapidity (positive rapidity is defined in the proton beam direction). As long as the acceptance and efficiencies for detecting l^+ and l^- are equal, this ratio of cross sections becomes simply the difference in the number of l^+ and l^- over the sum. Further, by CP invariance, the asymmetry at positive eta is equal in magnitude and opposite in sign to that at negative eta, so the value at positive eta is combined with that at negative eta reducing the effect of any differences in the efficiencies for l^+ and l^-.

W candidate events were required to have missing transverse energy $\not{E}_T > 25GeV$ (in the case of muons after correcting for the muon's momentum) and lepton transverse energy $E_T > 25GeV$. To further reduce QCD background, events with a jet whose E_T exceeded $20GeV$ were rejected. Preliminary estimates of the backgrounds and trigger acceptance suggest that systematic errors will not impact the measurement greatly.

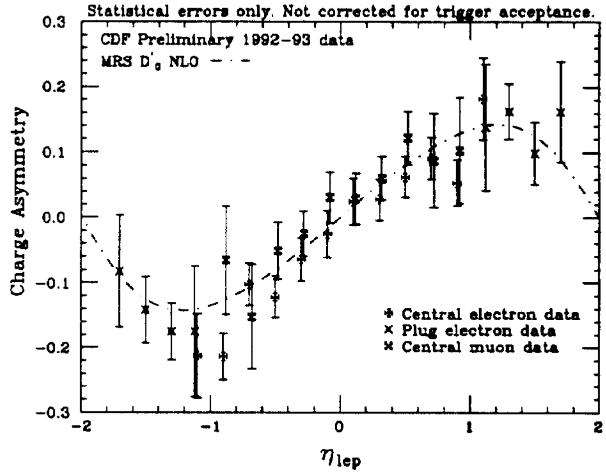

Figure 1: The charge asymmetry, as a function of lepton η found in each of the detector types (Central EM, Plug EM and Central Muon).

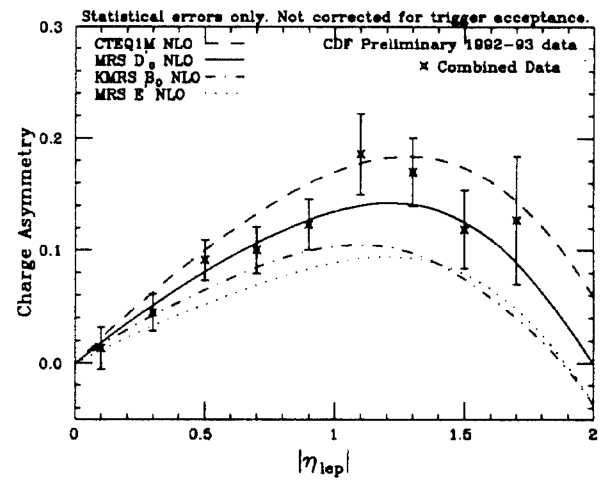

Figure 2: The charge asymmetry of the combined electron and muon data.

Figure 1 shows the asymmetry before the values at positive η are combined with the opposite asymmetry at negative η. The level of agreement between the various detector types strongly suggests that systematic effects are indeed small. Figure 2 shows the asymmetry in the combined data along with next-to-leading order (NLO) calculations [2] made using several sets of parton distributions. Our data favors the MRS D_0' and clearly excludes the older MRS E' distribution. NLO calculation of MRS D'_- and MRS S_0' are also made and their asymmetry predictions are very similar to that from MRS D_0' and agree well with our data. Already the asymmetry is showing sensitivity to the proton's structure at the level of the deep inelastic scattering experiments.

The W charge asymmetry is particularly sensitive to the slope of the d/u ratio versus x [3], whereas the $F_2^{\mu n}/F_2^{\mu p}$ measurements are sensitive to the magnitude of this ratio. Recently NMC has measured $F_2^{\mu n}/F_2^{\mu p}$ [4] over an x range comparable to that accessible at CDF (though at a very different Q^2). Their data, after correcting for shadowing effects [5, 6], is plotted in figure 3 along with several NLO predictions. Also shown are the d/u ratios after being shifted by a constant so they agree with MRS D_0' at $x = 0.2$. The distributions which predict the largest difference between the d/u ratio at small x and that at moderate x, also predict the largest charge asymmetry.

One sees that even though MRS D_0' and

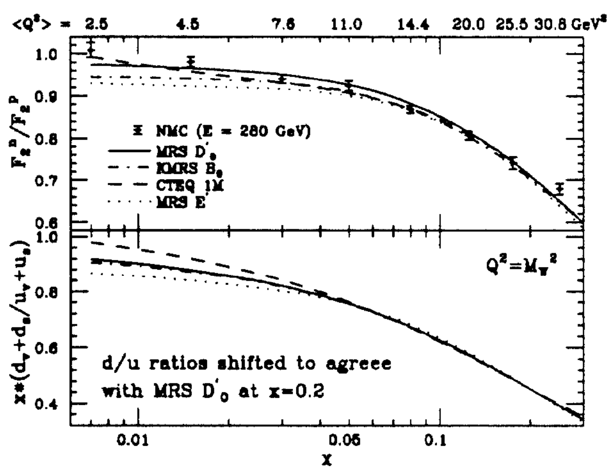

Figure 3: NMC data [4] corrected for shadowing effects [5,6] compared to a NLO calculation of F_2^n/F_2^p and the d/u ratios (shifted to agree at $x = 0.2$) for the same x range.

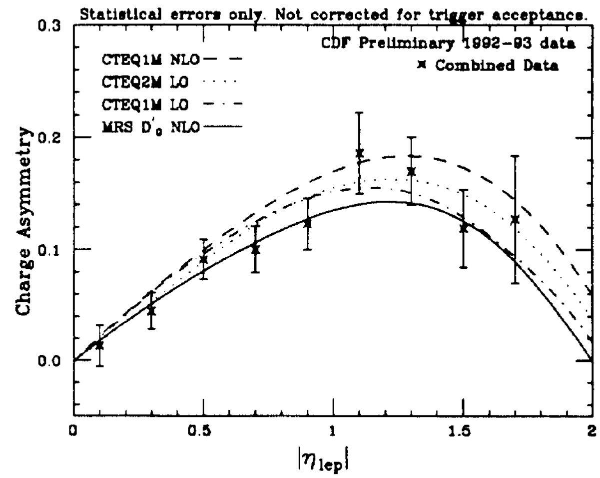

Figure 4: The charge asymmetry with LO CTEQ2 prediction

CTEQ 1M have very different d/u distributions (and thus very different charge asymmetry predictions) the $F_2^{\mu n}/F_2^{\mu p}$ predictions are similar. This is because $F_2^{\mu n}/F_2^{\mu p}$ ratio is also sensitive to the differences in the $\bar{u}$ and $\bar{d}$ distributions, whereas the $A(y_l)$ asymmetry is not. For example, the CTEQ's parameterization of the $\bar{u}$ and $\bar{d}$ sea distributions compensates for their steep d/u ratio and leads to a prediction for $F_2^{\mu n}/F_2^{\mu p}$ which is somewhat consistent with the NMC data but is less consistent with our $A(y_l)$ asymmetry measurement.

Very recently, the CTEQ group has released a new set of parton distribution functions (CTEQ2). Preliminary look of the LO CTEQ2 prediction with CTEQ1 LO prediction is shown in figure 4. From this plot, one can not conclude that CTEQ2 calculation has improved the consistency with our W asymmetry data. NLO CTEQ2 prediction calculation is in progress.

Since the errors in our data are very much dominated by the statistical errors, the expected four times increase in the total luminosity of the up coming Tevatron collider run (1b) would cut the existing errors in half. Therefore, we expect even more accurate measurement of the proton's structure from the collider data in near future.

3. Z' Search

Neutral gauge bosons in addition to the Z^0 are expected in many extensions of the Standard Model. These models typically specify the strengths of the couplings of the Z' to quarks and leptons but make no predictions for the Z' mass. Previous searches by CDF in the ee and $\mu\mu$ channels have yielded a combined lower limit for the Z' mass of 412 GeV/c^2 (95% C.L.) [7], assuming the standard coupling strengths. We report on a search by the CDF collaboration for direct production of Z', in the ee decay mode, from 21.4 pb^{-1} of data collected during the recent 1992-93 Collider run at Fermilab.

The data were collected with a three level trigger. The first level was satisfied by any calorimeter tower with transverse energy (E_T) above a set of thresholds individually specified for the various components of the calorimeter. The transverse energy is defined as the energy in a calorimeter cell times $\sin(\theta)$, where θ is the angle of the vector joining the center of the interaction region and the center of the cell with respect to the proton direction. The Level 2 trigger used in this search required a cluster in the central electromagnetic calorimeter (CEM) with $E_T > 9$ GeV in coincidence with a track in the central tracking chambers (CTC) of transverse momentum (P_T) > 9.2 GeV/c, as measured by the fast tracking processor. The efficiency of the CEM trigger is measured to be 0.91 ± 0.02 for electrons of $P_T > 20$ GeV/c, independent of P_T. A software Level 3 trigger increased the thresholds to 22 GeV and 13 GeV/c for E_T and P_T respectively. It also required a second EM cluster of $E_T > 20$ (15) GeV in the central (plug) calorimeter. The event selection required a good vertex within $\pm$ 60 cm from the center of the interaction region, one electron candidate in the central calorimeter ("tight cut"), and a second electron candidate defined with less stringent requirements ("loose cut") in the central or plug calorimeters. The choice of cuts reflected the goal of maintaining high efficiency at large electron energies. Both electrons are required to have $E_T > 25$ GeV and be in the fiducial region. Central electron candidates are also required to have an associated track with $P_T > 13$ GeV/c, matching the calorimeter cluster. Further "tight" and "loose" cuts are listed below:

- Central Electron "tight cuts":
  - $E_T/P_T < 4.0$ or $P_T > 100$ GeV.
  - Had/Em $< .055 + .045{*}E/100$
  - $ISO < 0.1$
- Central Electron "loose cuts"
  - Had/Em < 0.125
  - $ISO < 0.2$
- Plug Electron "loose cuts"
  - $\chi^2 < 3.0$
  - $ISO < 0.2$

The electron isolation is defined as ISO $= \frac{E_t^{cone} - E_t^e}{E_t^e}$, where E_t^{cone} is the transverse energy in a cone of $\Delta R < 0.4$ around the electron and E_t^e is the transverse energy deposited by the electron. Had/em is the ratio of the hadronic and electromagnetic energies in the electron cluster. Since the CTC does not cover entire plug region, we do not use, for plug electron candidates, any cuts which involve tracking information. Instead, we apply a cut on the χ^2 of the transverse profile of the cluster. The cut value was determined from the test beam data.

Efficiencies of the analysis cuts were determined using a sample of dielectron events from Z decays, defined as ee pairs selected by electron identification requirements which are strict but uncorrelated with the studied cuts. The total efficiency for 'tight' cuts in the Central region is 92.3% $\pm$0.8%; for the 'loose' cuts in the Central region is 94.5% $\pm$0.6% and 95.5% $\pm$0.6% the Plug region.

The invariant mass distribution of ee pairs for $M_{ee} > 40$ GeV/c^2 is shown in Fig. 5. The final sample consists of 1346 events, of which 625 have both electrons in the central calorimeter and 721 have one leg in the central and one in the plug calorimeter. The largest mass event is at 320 GeV/c^2.

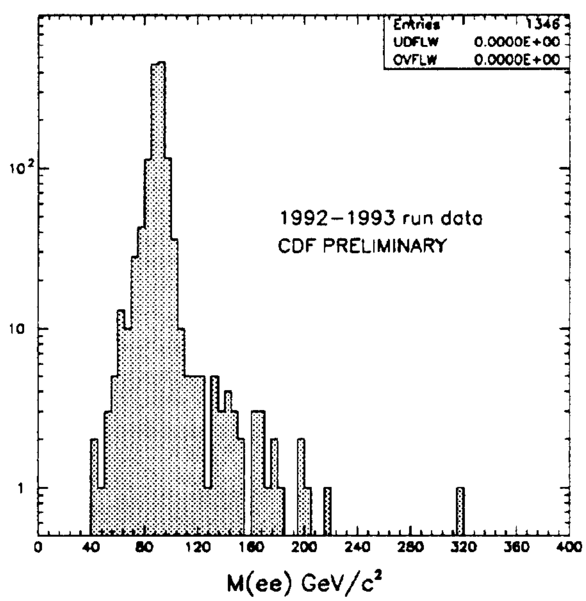

Figure 5: Invariant mass distribution of dielectrons.

The geometrical and kinematical acceptances of the detector were determined from samples of Z and Z' of different masses generated with a simple Monte Carlo simulation. Electron pairs were generated according to the MRS D'_{-} parton distribution functions (p.d.f.). Different sets of p.d.f. are used to estimate systematic uncertainties (1.2%) to the acceptance due to this choice. An uncertainty of 2% from the assumption of the boson p_T distribution in the generator is estimated by changing that distribution by $\pm$25%. An overall systematic uncertainty of 10% is derived, including uncertainties due to detector acceptance, efficiency of the event selection cuts and luminosity normalization (7%). [11]. For our choice of p.d.f. the acceptance is 34% at the Z peak and rises to a roughly constant value of 52% for Z' masses of 200 GeV or above. As a check, we calculate Z boson cross section using the number of observed Z candidate events in our Z' search sample and obtained efficiencies and acceptance values. We find the Z cross section to be in very good agreement with CDF published Z cross section value, 0.209$\pm$0.013(stat)$\pm$0.017(syst) nb. This is measured from the dielectron decay mode of Z bosons [9]. In the high invariant mass region where we are searching for Z', the major background is coming from the Drell-Yan process. We have estimated numbers of events we expect from the Drell-Yan process normalizing to 21.4 pb^{-1} of integrated luminosity. We expect approximately 1 event with dielectron invariant mass above 250 GeV/c^2 and 0.5 event above 300 GeV/c^2. We observe one event in this region with a mass of 320 GeV/c^2 in good agreement with the Drell-Yan expectations.

To obtain a limit on $\sigma(Z') \cdot B_{ee}$, we fit the observed dielectron invariant-mass distribution to a superposition of predicted distributions from the Standard Model Drell-Yan process and Z' production of a given mass using a binned maximum-likelihood method [10]. The fit is repeated for a variety of Z' masses in the range 100 - 600 GeV/c^2. SM couplings are assumed in generating the Z' events and the Z' width is set equal to the Z^0 width scaled by a factor $M_{Z'}/M_{Z^0}$. To calculate the branching ratio to dielectrons we have assumed a top mass of 150 GeV/c^2. For each Z' mass considered, the systematic uncertainties discussed above are numerically folded into the likelihood function [10]. The 95% C.L. upper limit on $\sigma(Z')\cdot B(Z' \rightarrow ee)$ is shown in Fig. 6. Assuming SM couplings, we determine a lower mass limit of Z' to be 495 GeV/c^2. Although we have assumed the standard coupling strengths to derive 95% C.L. $\sigma(Z')\cdot B$ limit curve as a function of dielectron mass, as shown in reference [7] we can use this curve to compare to a wide variety of the theoretical Z' model predictions. Figure 7 shows our 95% C.L. limit curve (solid line) along with predictions from four popular E_6 models (dashed lines)[12]. In each plot the upper dashed curve corresponds to the model's prediction for Z' decaying only to known fermions; the lower dashed curve is the expectation for Z' decaying to all known fermions, supersymmetric s-fermions, and exotic fermions that occur in the representations of the model.

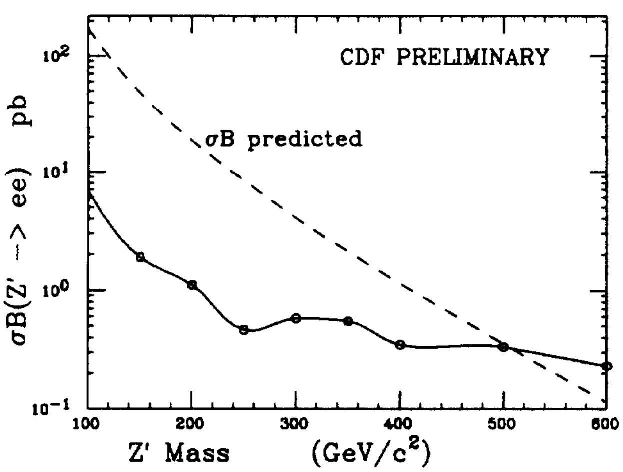

Figure 6: The 95% C.L. limit on $\sigma(Z')\cdot B_{ee}$ for Z' production. The points on the lines represent the set of $M_{Z'}$ values at which the fits are performed. The dashed line is the prediction of $\sigma(Z')\cdot B_{ee}$ assuming SM couplings

Acknowledgements

I would like to thank Mark Dickson for his help in preparing material for this talk on

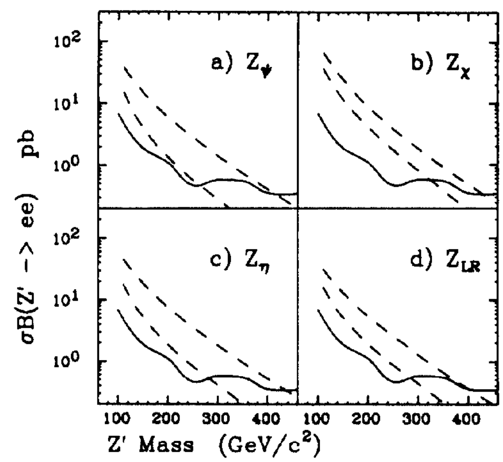

Figure 7: The 95% C.L. lower mass limits for the four different Z' models from the E_6 symmetry group.

W charge asymmetry analysis. I also would like to thank members of Z'/W' analysis group, Pawel de Barbaro, Giorgio Chiarelli, Carla Grosso-Pilcher, Bob Kephart, Manoj Pillai, and Qifeng Shen. On behalf of the CDF Collaboration, I would like to thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Science, Culture, and Education of Japan; the Natural Sciences and Engineering Research Council of Canada; the A. P. Sloan Foundation; and the Alexander von Humboldt-Stiftung.

References

[1] F. Abe et al., *Nucl. Inst. and Meth.* **A271**(1988)387.

[2] W. Giele, E. Glover, D.A. Kosower, Higher Order Corrections to Jet Cross Sections in Hadron Colliders, Fermilab-Pub-92/230-T (1992).

[3] A.D. Martin, R.G. Roberts and W.J. Stirling, Mod. Phys. Lett. **A4** (1989) 1135.

[4] NMC Collab., P. Amaudruz *et al.*, Phys. Lett. B 295 (1992) 278.

[5] A.D. Martin, R.G. Roberts and W.J. Stirling, Phys. Lett. B 306 (1993) 146 figure 2.

[6] B. Badelek, J. Kwiecinski, Nucl. Phys. B 370 (1992) 278.

[7] CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **68**, 1463 (1992).

[8] CDF Collab., F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **271**, 387 (1988).

[9] CDF collab.,F. Abe *et al.*, Phys. Rev. D **44**, 29 (1991).

[10] CDF Collab., F. Abe *et al.*, Phys. Rev. D **43**, 664 (1991).

[11] CDF Collab., F. Abe *et al.*, Phys. Rev. D **44**, 29 (1991).

[12] F. del Aguila, M. Quiros, and F. Zwirner, Nucl. Phys. **B287**, 457 (1987); D. London and J. L. Rosner, Phys. Rev. D **34**, 1530 (1986); F. del Aguila, J. M. Moreno and M. Quiros, Phys. Rev. D **41**. 134 (1990), and references therein.

[13] E. Eichten, K. Lane, and M. Peskin, Phys. Rev. Lett. **50**, 811 (1983).